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LUMINESCENCE AT HIGH TEMPERATURES

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It is the purpose of this note to announce the discovery of luminescence at temperatures above those at which ordinary phosphorescence disappears and fluorescence, excited by light, reaches extinction: in a word, roughly speaking, above the beginnings of a visible red heat.

Luminescence at these higher temperatures has probably remained unnoticed¹ because the usual source of excitation has been light and photo-excitation, as was observed by Lenard and Klatt² in their studies of the phosphorescent sulphides, generally ceases below 400° C. The experiments of Wiedemann and Schmidt³ on the effect of temperature on the kathodo-luminescence of certain substances reached their upper limit at about the same temperature, not because the materials ceased to glow but on account of the softening of the glass of their vacuum tubes.

The main facts about this luminescence at high temperatures, the details concerning which will be given in a series of forthcoming papers, may be briefly stated as follows:

1. *The glow is produced by a new type of excitation*, i. e., by contact with the outer zone of the hydrogen flame; also in some instances by kathode bombardment and the action of X-rays.

2. *The effect is quite distinct from photo-luminescence*, from which it differs in the following respects:

(a) It is observable in many substances incapable of excitation by light; such as the oxides of calcium, zinc, magnesium, aluminum, silicon and zirconium; and in sulphides of calcium and zinc of such purity as to be non-phosphorescent.

(b) It is absent in some strongly fluorescent materials such as willemite and calcium tungstate.

(c) The addition of a trace of some activating substance, as in the production of the phosphorescent sulphides, is not necessary. Such an admixture sometimes modifies the color of the glow but more frequently prevents fluorescence altogether. Thus many of the Lenard and Klatt sulphides and the well-known, red glowing, cadmium phosphate of Andrews are inert under the excitation of the flame.

(d) Where photo-fluorescent substances are active, as in Sidot blende, Balmain's paint and several of the phosphorescent sulphides, the luminescence has an upper limit of temperature far above that at which photo-excitation ceases.

3. *Distinguishing features in relation to temperature radiation*.—The effect often occurs at temperatures far below the red heat. When superimposed upon the red heat it is readily distinguishable:

(a) *By its color*, which is more often green, blue or white than ruddy.
(b) *By its law of decay*, which is that of vanishing phosphorescence instead of the law of cooling.

(c) *By its spectrum*, which is a characteristic broad banded fluorescence spectrum often lacking altogether in the red. The bands of these spectra are made up of over-lapping components which form series with the usual uniform frequency intervals.

4. *Limits of Activity*.—The upper limiting temperature (or temperature of extinction) differs with various substances. It is, for example, about:

- 690° C. for calcium oxide,
- 740° C. for calcium sulphide,
- 940° C. for zinc oxide and pure zinc sulphide.

The lower limit also varies through a very wide range; e. g., from

- 52° C. for aluminum oxide to
- 568° C. for the blue-green band of zinc oxide.

These limiting temperatures are in some cases very sharply defined.

5. *Individual excitation of bands*.—The over-lapping bands of the spectrum are separately excited and each has its particular active range of temperatures. As these differ, color changes with temperature result. In some cases the temperature ranges do not over-lap, so that two or even three fluorescences follow one another as the temperature rises. Thus zirconium oxide shows a bluish white fluorescence between 76° C. and 372°, followed by deep red between 440° and 720°.

6. *Kathodo-luminescence at high temperatures*.—Many of the substances which exhibit flame excitation are also luminescent in the kathode tube, and sometimes we find the same bands brought out and the same upper temperature of extinction.

Thus calcium oxide becomes extinct at about 690°, whether excited by the hydrogen flame or by kathode bombardment.

Sometimes the two types of excitation give strikingly different appearances, as in the case of the synthetic ruby, which shows the same pale green band as other forms of aluminum oxide in the flame but the well known brilliant red in the vacuum tube. Our observations indicate that under cathodic action also the bands are independently excited and that bands of shorter wave-length have a higher temperature range: Thus the color shift towards violet with heating recorded by Crookes and later systematically studied by Wiedemann and Schmidt (*l. c.*) is confirmed and explained.

7. Excitation by means of X-rays at these temperatures has thus far been tried only with a few substances. It was found, however, that calcium oxide, calcium carbonate, sidot blende and some of the phosphorescent sulphides which are subject to flame excitation respond also

to X-rays at temperatures up to a dull red heat. There is usually color change as mentioned under (6) and a distinct maximum of brightness at some intermediate temperature.

¹ In this statement reference is to *established* cases of luminescence. Exception is made of the rather numerous instances in which radiation of an unusual character is *ascribed* to luminescence without actual demonstration of the fact. The present author more than once has made such assumptions and believes them likely to be verified.

² Lenard and Klatt, *Ann. Physik, Leipzig*, **15**, 1904 (425).

³ Wiedemann and Schmidt, *Ibid.*, **56**, 1895 (218).

FUNCTIONAL REGULATIONS IN ANIMALS WITH COMPOSITE SPINAL CORDS

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In several recent series of experiments,¹ involving the transplantation of the forelimb in *Amblystoma* embryos, a number of points were brought out by the author bearing upon the question of the functional readjustment of the peripheral nervous system in response to the altered conditions. The cardinal points may be summarized as follows:

(1) When the limb is transplanted to an abnormal (heterotopic) position, there is a striking tendency for its innervation to be derived from the original limb level of the cord, and only when this is totally or in part accomplished, is the limb capable of movements which are well coördinated with those of the opposite intact appendage.

(2) Transplanted limbs which are not supplied by the normal limb nerves exhibit a degree of function which is directly correlated with the region of the spinal cord from which the nerves are derived. The motility of the appendage is more perfect when its nerves come from segments of the cord adjoining those which contribute the normal limb nerves.

(3) The gradual loss of function as limbs are transplanted further and further away from the normal situation is attributed to increased defective connections within the central nervous system and not to a corresponding decrease in effective peripheral efferent innervation nor to deficiencies in the skeleto-muscular mechanism of the limb and the shoulder girdle.

(4) Peripheral nerves supplying a transplanted limb are larger than their counterparts which have no connection with a limb. Critical examination has shown this enlargement to be due to a hyperplasia of the afferent neurones with no evident over-production of cells on the motor side.

The fact that structurally complete transplanted limbs with an adequate peripheral nervous mechanism, derived from the extra-limb level